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Estimate Yengisogat Glacier Surface Flow Velocities Using ALOS PALSAR Data Feature-tracking, Karakoram,China*

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Abstract

Little is known about the detailed behavior of glaciers in the Karakoram Mountains. The Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) data were used to obtain the surface velocity of the Yengisogat Glacier in the Karakoram Mountains. Four data sets covered all four seasons to extract the offset fields and estimate annual average surface velocity based on seasonal velocities. For the ALOS PALSAR data, the Synthetic Aperture Radar (SAR) feature-tracking (SFRT) was utilized instead of SAR interferometry because of low coherence in fast moving glaciers or large time intervals between the acquisitions of images. The accuracy of measurements was discussed and measurements were consistent with previous results. We find that there were two fast moving glacier flows existed in south tributaries of the glacier.

Keywords:Glacier surface flow; SAR feature-tracking; Karakoram Mountains

1. Introduction

Mountain glaciers are sensitive indicators of climate fluctuations [1]. All glaciers in western China have retreated to some degree with precipitation and temperature increases during the last half century [2].

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The Karakoram Mountains are one of the most remote and least accessible mountain ranges in the world, where many surges have occurred historically [3-6]. Little is known about the behavior of the glaciers in the Karakoram Range and almost no field work has been completed. There are no ground measurements from the Yengisogat Glacier, the largest glacier in China [7]. As temperatures continue rising there will likely be a greater number of glacier lakes outburst floods (GLOFs) threatening downstream communities [8, 9]. Therefore, more attention should be paid to these glaciers, with research focusing on factors such as glacier temperature and velocity fields.

Glacier surface flow velocities are direct indicators of glacier mass balance or surge and are used to understand glacier dynamics [10-13]. The use of satellite SAR has been shown to be a feasible method to measure glacier surface flow rates and has advantages over other traditional methods which could retrieve glacier surface velocity faster and less costly.

In this study, the SAR feature-tracking (SRFT) technique is used to retrieve glacier surface rates because the large time intervals between acquisition of the SAR images from SAR interferometry limits the loss of glacial flow coherence. This method is less precise than SAR Interferometry but more robust and has been used to calculate the surface flow velocity of fast moving glaciers such as Sortebræ Glacier in Greenland [12, 14-17] and glaciers in the Himalayan regions [19].

Surface flow rates of the Yengisogat Glacier are calculated from offset tracking of the ALOS PALSAR image in combination with the digital elevation model (DEM) 90 meters resolutions. Then the calculated surface flow velocity was validated using the previous results.

2.Study Area

The Yengisogat Glacier is located in the Karakoram Mountains of western China at ~36.0° N, ~76.0° E. Also known as the Skamry Glacier, the Yengisogat is a mid-latitude, subpolar glacier [18]. No in situ field work has been carried out for this glacier; the only data available is from a topographic map obtained by aero photogrammetry in the 1970s. This glacier was also named crevasses glacier [7, 19] because so many crevasses and seracs were observed from the aero photos, extending almost to the snowline, which is why ground measurements are impossible. The Yengisogat Valley is oriented from northwest to southeast, including four main tributaries and several little glacier flows. The glacier trunk was about 42 km long measured, as from aero photos and occupied ~379.97 km2. The summit of this glacier is 7050 meters above sea level (m a.s.l) and the terminus is 4000 m a.s.l.

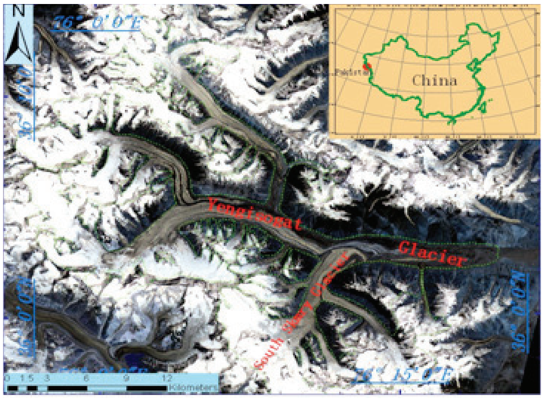

Fig. 1. Map of research region, with main features labelled and located. The red area in the inset map indicates the position of the study area. The background is Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) imagery (26-05-2007). The green line is the border of the Yengisogat Glacier from the First Chinese Glacier Inventory.

3.Data Sources And Methods

3.1 . Data Sources

The ALOS Satellite was launched in early 2006, with data collected by the PALSAR sensor at L-band (λ =23.5cm). ALOS PALSAR data including Fine Beam Single polarization mode (FBS) and Fine Beam Double polarization mode (FBD) were collected by the Japan Aerospace Exploration Agency (JAXA). The information from available ALOS PALSAR data covered almost an entire mass balance year, as Table 1 shows.

TABLE 1
ALOS PALSAR SCENES COVERING THE STUDY AREA AND USED IN THE APPLICATION OF SRFT TO DERIVE GLACIER SURFACE FLOW VELOCITY

ID	*Image 1*	*Image2*	*B⊥*(m)*
	date	*date*	
Autumn	10-08-2007	25-09-2007	112*
Winter	26-12-2007	10-02-2008	925
Spring	10-01-2008	27-03-2008	97 *
Summer	30-06-2009	15-08-2009	44 *

$B_{\perp}$* is Perpendicular Baseline (meters). All images are in ascending orbit. All data pairs employed for SRFT are within 46 days of acquisition time intervals. Data employed are Single-look Complex (SLC). Because no suitable image pair was available for summer 2008, i.e., too long perpendicular baseline, the data pair of summer 2009 was selected instead.

As shown in Table 1, perpendicular baselines of image pairs indicated are proper for SAR interferometry except for the winter pair. But for ALOS PALSAR data, data pair acquisition time intervals are within 46 days, which made the image pairs coherence too low to retrieve clear interferograms, especially in glacier regions [10, 14].

3.2 Methods and Errors

SAR feature tracking is implemented by calculating the offsets between two SAR images using offset tracking procedures including intensity tracking and coherence tracking. The co-registration offsets of two PALSAR images in both ground range and azimuth directions are generated and employed to calculate the displacement of the glacier's surface (Gray and others, 1998; Pritchard and others, 2005;Strozzi and others, 2002). The estimated offsets are unambiguous values, which means there is no need for phase unwrapping, which is one of the most critical steps in SAR interferometry. In this study, horizontal offsets in radar geometry were extracted from the co- registered data pairs using GAMMA Software and processed within ARCGIS software 9.3(ESRI).

The main errors are related to the co–registration, transformation of offset to surface flow velocity, and systematic errors [14, 16, 20]. The theoretical errors in horizontal direction is roughly the sum of the range and azimuth errors [14].This method was applied to estimate the theoretical errors of SRFT. The errors include the systematic noise and the ionospheric effects, which could be regarded as a constant while testing the stable area [12, 14, 21].The static areas such as rocks were tested to provide the systematic errors in this research. For ALOS PALSAR FBS data and FBD data the errors in horizontal direction are listed below.

TABLE 2
THEORETICAL ERRORS AND ERRORS IN THE STABLE AREA

	Data pairs		*Theoretical errors (md^{-1})*	*Errors in stable Area (md^{-1})*
ID	*First orbit*	*Second orbit*		
Autumn	08222	08893	0.01	0.039
Winter	10235	10906	0.022	0.076
Spring	10906	11577	0.008	0.026
Summer	18287	18958	0.007	0.017

The values of theoretical errors in Table 2 are roughly computed by the method referred to above. For example, the theoretical value of errors to the autumn pair is 0.01md^{-1}, which was calculated by 9.368×0.017+3.153×0.085≈0.43m in 46 days (equivalent to 0.01md^{-1}). The other pairs' relative errors were also estimated by this method. The errors of annual average velocity are ~14 m yr^{-1}, computed by the average of errors of four measurements. Obviously, the errors of data pairs in winter are much larger than that of any other pair and this would make it incomparable when the two values are close.

Some abnormal values from the original results of offset-tracking processing can be filtered using methods described by Dwyer [10, 22] or other classic filtering methods such as the Lee filter. For most inland glaciers, average velocity was less that 0.5md-1 [23]. We simply replaced the abnormal values which are larger than 1 md-1 and filtered with the Lee filter by 5×5 pixels because of surging or fast moving ice, as described in previous studies of the region [4, 6, 24].

4.Results

In examining obtained glacier surface flow velocities, it was obvious that there were two clear glacier flows, with the south tributaries moving faster than north tributaries.

The following figures (Fig. 2) reveal the seasonal velocity distribution, which covered almost an entire glacier mass balance year.

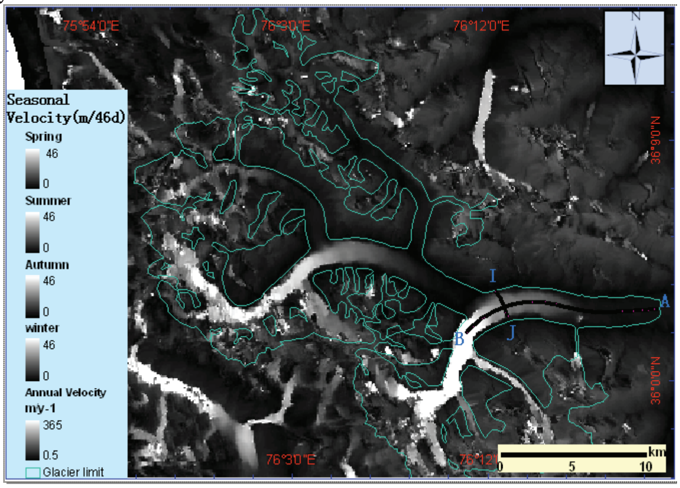

Fig. 2. The glacier surface velocity fields from SRFT. Velocities were not shown where they were less than the errors estimated in each image pair, as mentioned in Table 1. For the sake of convenience, SRFT results were also identified by the acquisition time: autumn is represented by the August 10, 2007 and September 25, 2007 data pair; winter by the December 26, 2007 and February 10, 2008 data pair; spring by the February 10, 2008 and March 27, 2008 data pair; and summer by the June 30, 2009 and August 15, 2009 data pair. Solid lins A-B in each figure follows the glacier flow line, I-J in each figure is the transverse profiles of the glacier flow. (only one seasonal velocity field was shown and velocity values above 1m/d were filtered).

Two fast moving glacier flows can be seen clearly in each seasonal surface velocity field and velocity of South tributaries were more quickly than north tributary.

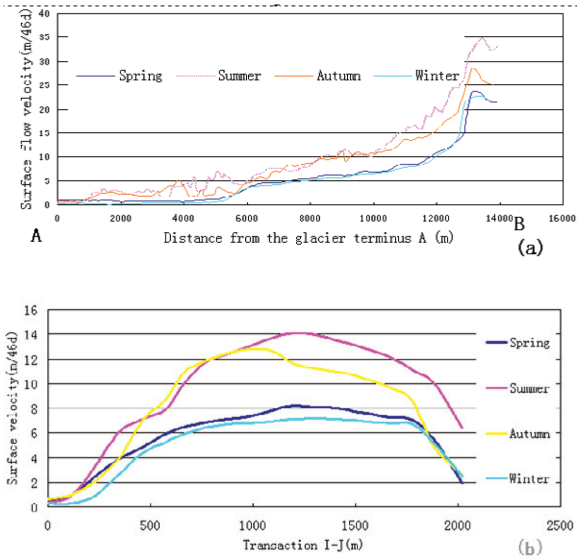

Fig. 3. Glacier surface flow velocity along central-flow line (A-B)(Fig.3 a) and in the transverse profiles I-J(Fig.3.b). The corresponding solid line A-B,I-J are displayed in Fig. 2.

It is clear that the seasonal glacier surface velocity change is according with the season change. Surface velocity is most fast in summer and slows down in winter. The surface flow velocities in summer more quickly than any other seasons.

The transverse surface flow velocities also follow the principle that velocities at a glacier's central flow line are the maximum and decrease toward the margins.

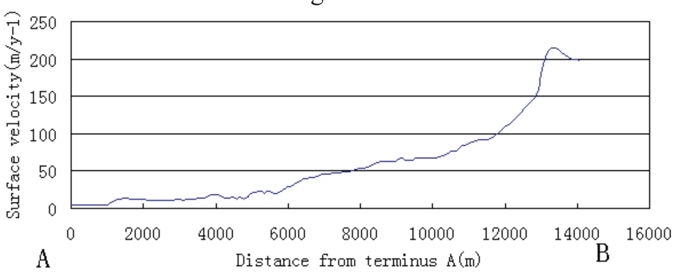

Fig .4. Annual surface velocity along central flow line A-B

The annual average surface velocities are agreement with previous work undertaken here using optical imagery feature-tracking [6].

5.Discussions And Conclusions

Comparing the velocity distributions along the central flow line, we find that the surface central flow of the two south tributaries are clearly seen and the average annual velocity is about 100 m yr-1, while the velocity of the north tributary is almost less than the errors (14 m yr -1). It is probably the aspect of the glacier which caused more solar radiance absorbed and more mass lost in the north tributaries than the south tributary.

SAR feature-tracking is a feasible method to retrieve glacier surface flow velocities, especially for cloud and snow cover areas where visible optical images do not work well, Although accuracy is lower relative to SAR interferometry, SAR feature-tracking can measure large acquisition time intervals of glaciers' surface velocity [25], and the results match fairly well with the previous study using optical imagery feature-tracking. As the results discussed above show, the south tributaries of the Yengisogat Glacier were moving faster than the northern tributaries. Changes to the glacier surface flow are due mainly to the aspect of the Yengisogat Glacier.

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